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The Position/Structure Stability of Four ICRF2 Sources

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Abstract

Four compact radio sources in the International Celestial Reference Frame (ICRF2) catalog were observed using phase referencing with the VLBA at 43, 23, and 8.6-GHz, and with VERA at 23-GHz over a one-year period. The goal was to determine the stability of the radio cores and to assess structure effects associated with positions in the ICRF2. Conclusions are: (1) 43-GHz VLBI high-resolution observations are often needed to determine the location of the radio core. (2) Over the observing period, the relative positions among the four radio cores were constant to 0.02 mas, suggesting that once the *true* radio core is identified, it remains stationary in the sky to this accuracy. (3) The emission in 0556+238, one of the four sources investigated and one of the 295 ICRF2 defining sources, was dominated by a strong component near the core and moved 0.1 mas during the year. (4) Comparison of the VLBA images at 43, 23, and 8.6-GHz with the ICRF2 positions suggests that the 8-GHz structure is often dominated by a bright non-core component. The measured ICRF2 position can be displaced more than 0.5 mas from the radio core and partake in the motion of the bright jet component.

1. Source Selection, Observations, Reductions, and Imaging

The Second Realization of the International Celestial Reference Frame (ICRF2) is defined by the positions of 295 compact radio sources located around the sky [1]. The position uncertainties for many of these sources is less than 0.06 mas, obtained by averaging decades of observations. This positional accuracy is presently limited by residual variable tropospheric refraction; however, with the improved modeling of the troposphere, the effects of variable source structure is becoming a comparable error component in determining the position of an ICRF2 source. Using interferometric phase referencing among four sources within a three-degree radius, the tropospheric effects largely cancel, and the structure effects with time and frequency can be more accurately determined.

The sources were selected to accommodate observations by the VLBI Exploration of Radio Astrometry (VERA) four-element VLBI array in Japan that can observe two sources simultaneously if they are separated by no more than 2.2°. A search of the 8.6-GHz ICRF2 catalog found several groups of sources, and we chose 0547+234, 0554+242, 0556+238, and 0601+245. They are all compact, and the source 0556+238 is one of the 295 defining sources in the ICRF2 catalog.

Four VERA sessions at 23-GHz and six VLBA sessions at 23-GHz and 43-GHz were observed between Apr 2008 and Dec 2009. One VLBA session at 8.6-GHz was added in Jan 2010. Because of the higher resolution of the VLBA and the use of 43-GHz, the major results of this paper will be obtained from the VLBA sessions alone. However, the VERA images were consistent with that of the VLBA.

For each VLBA session, the observing sequence used was a repetition of 0556-0547-0556-0554-0556-0601-0555-0547. Each scan was 18 sec in length, with 10 sec needed for source switching. The separation between the center of two 0556+238 scans was only 55 sec, sufficiently close in time to maintain phase coherence at 43-GHz except under adverse weather conditions or for observations at low elevations. The basic sequence among the four sources took 3 min, and ten sequences were made over a 30-minute period. These 30-minute blocks were then alternated between 23-GHz and 43-GHz observing frequencies. The center frequencies were at 22.45-GHz and 43.41-GHz.

The data were calibrated using 0556+238 as the primary reference to determine the delay and phase associated with the clock offsets, the astrometric model errors, and the troposphere delay in the vicinity of the sources. After calibration, each source for each session and frequency was imaged, cleaned and then phase self-calibrated, using the initial reference image. In this way, the image quality was improved, but the astrometric information was unchanged to a level of 0.01 mas.

2. The Morphology and Evolution of Each Source

The VLBA images for five sessions for the sources at 43 and 23-GHz are shown in Figure 1. From analysis of the images, the radio core component for each source could be ascertained using some or all of the following properties: flat spectral index, location at the end of the structure, compactness, and lack of proper motion. The core components are labeled for each source by the symbol **0**, with other numbers used to designate other components. Without these high-resolution high-frequency data, determination of the core would have been ambiguous for 0554+242, 0556+238, and 0601+245.

The images, all registered with respect to 0556+238, showed that the radio cores of 0547+234, 0554+242, and 0601+245 were moving in the southern direction by about 0.1 mas/year! This suggested an astrometric problem with the phase reference calibrator. Careful modeling of its structure at 23 and 43-GHz showed that the source was composed of two close components: the brighter component to the north and a fainter component to the south, with a separation that increased from 0.1 to 0.2 mas during the year. The weaker southern component has a flat spectral index and its motion was consistent with the other three radio cores. Hence, it is the radio core for 0556+238 and has been labeled as **0** in Figure 1. Additional analysis of previous observations of this source at 23-GHz and 8.6-GHz also suggest that its position over the years has been somewhat unstable [3, 4].

The relative position of the four radio cores change by less than about 0.02 mas/yr over the observational period. This result demonstrates that once the location of the radio core is identified with the emission from a radio source, its position is stable to the above accuracy. Future comparison of the core position of radio sources and the position from future space-optical interferometers can, thus, in principle be made at the tens of microarcsecond level.

3. Comparison with the ICRF2 and the VLBA 8.6-GHz Positions

The comparison of the ICRF2 position, the VLBA 43-GHz image and the VLBA 8.6-GHz image (Jan 2010) for each source is shown in Figure 2. For the three sets of images, 0556+238, even with its internal structure changes, was used to align the VLBA 43 and 8.6-GHz positions with the ICRF2 catalog. The position of $\alpha = 05^h59^m32.03313165^s, \delta = 23°53'53.9267683''$, with an estimated error of 0.04 mas in both coordinates, was assumed to lie between the two components at 43-GHz with an estimated error of about 0.1 mas to overlap either component. For the VLBA 8.6-GHz image, the northern component is much brighter than the southern component, hence

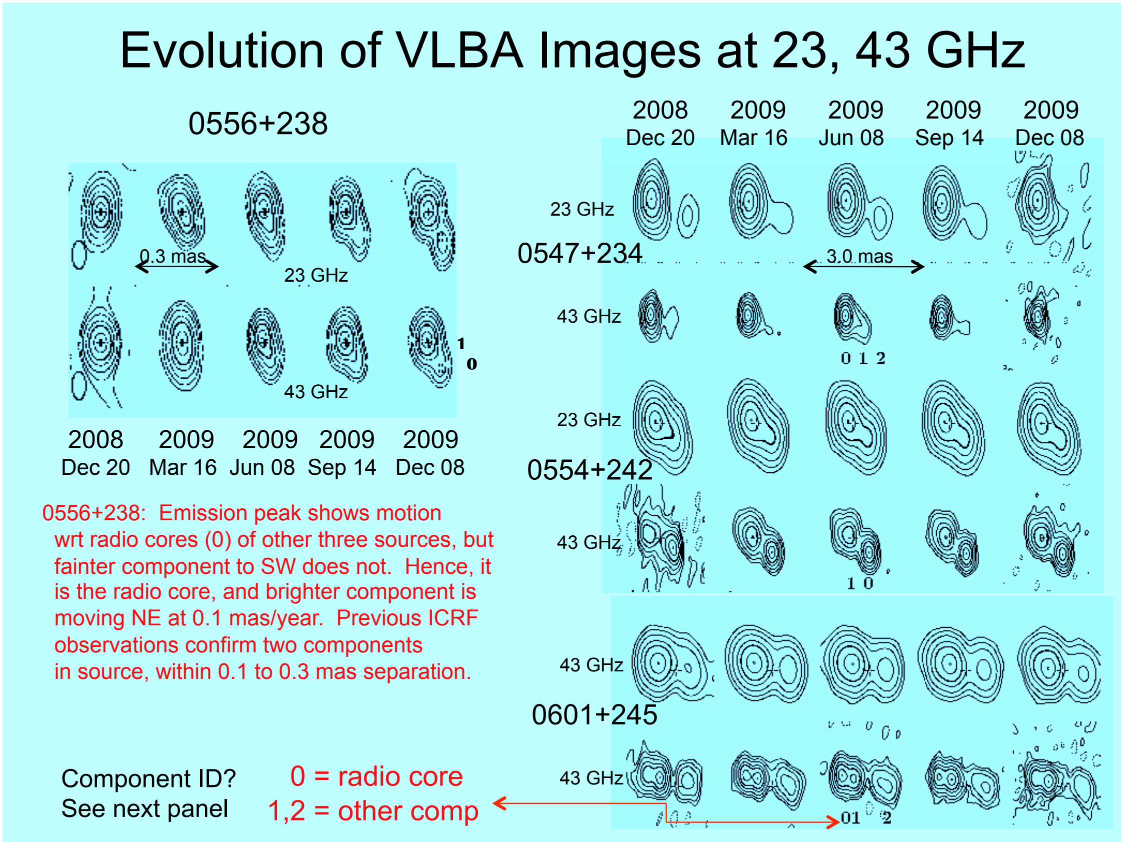

Figure 1. Evolution of the four sources: The left side of the figure shows the structure change of 0556+238. The radio core is identified with the southern component that is clearly seen in the last two sessions. The right side of the figure shows the evolution of the other three sources. The number labels are for the components in each source: **0** is the radio core; **1** and **2** are the additional components. The + shows the location of the assumed phase center for each source.

the peak intensity at this frequency was assumed to be located at the peak emission location of the northern component of the 43-GHz image. These alignment uncertainties, however, are considerably smaller than the large position offsets described in the next few paragraphs.

Although 0547+234 is dominated by a strong radio core, the ICRF2 position, the 43-GHz core position, and the 8.6-GHz position in Jan 2010 are all significantly different. Since this source was not frequently observed during the ICRF2 sessions over the last few decades, the estimated position error may be underestimated. The displacement in the VLBA 43-GHz and VLBA 8.6-GHz position is significant, however. The position at 8.6-GHz may be influenced by the blending of the diffuse emission to the west, blending with the core more strongly at the lower frequency. This source gives a good example of core-shifts with frequency that have been observed for other compact radio sources [5].

The double structure of 0554+242 produces different position estimates, depending on the frequency and resolution. At 43-GHz, the western component is clearly identified as the radio core, and its position should be associated with that of the source. The 8.6-GHz VLBA image, on the other hand, is dominated by the strong, steep-spectrum eastern component, and its position is

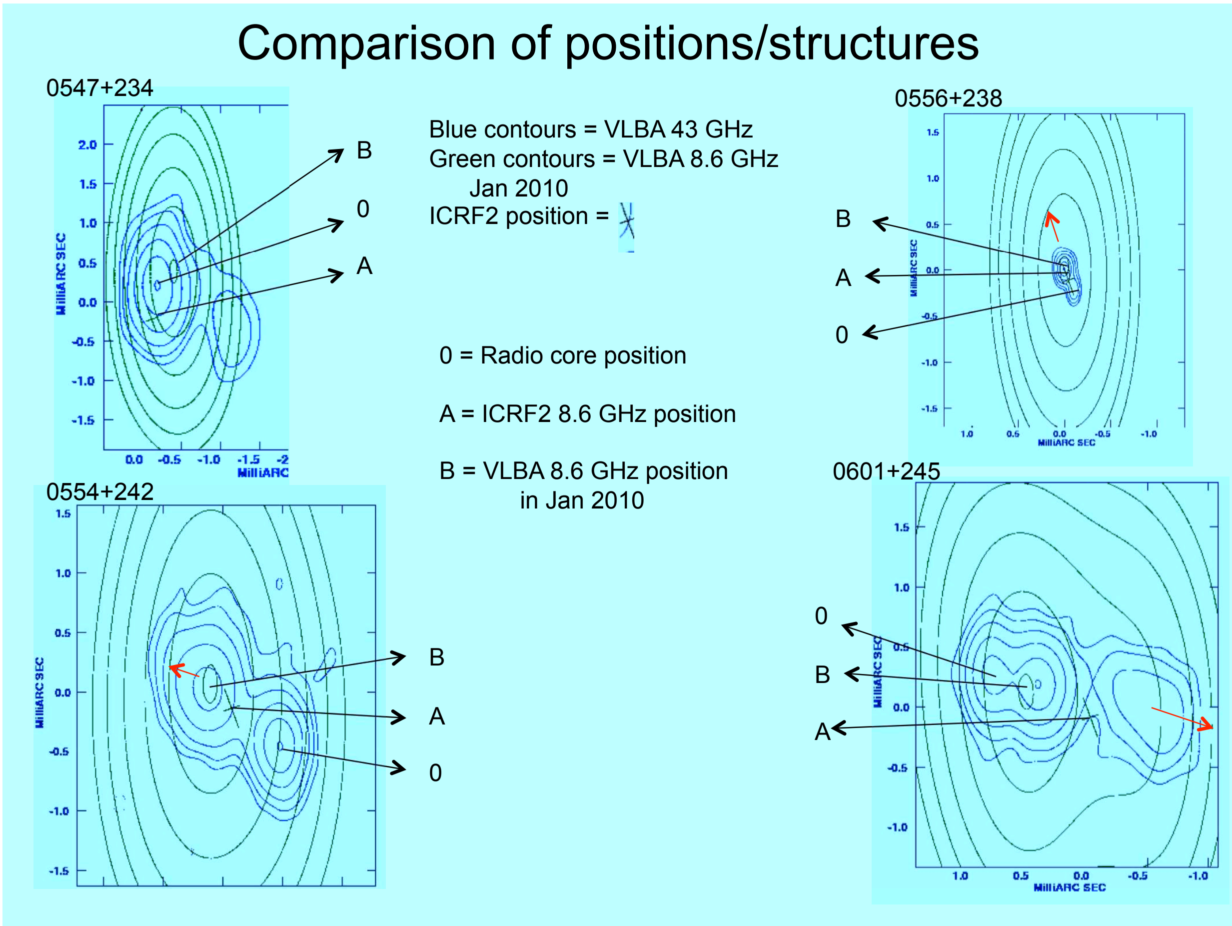

Figure 2. The comparison of the positions and structure of the four sources: The 8.6-GHz Jan 2010 VLBA structures are shown by the green contours (the larger oval and quasi-oval lines). The 43-GHz Dec 2009 VLBA structures are shown by the blue contours that are well within the 8.6-GHz structure. The ICRF2 position is shown by the tilted cross and is labeled by **A**. The radio core position is labeled by **0**, and the VLBA 8.6-GHz position in 2010 is labeled by **B**. The motions of some components are indicated by the arrows.

considerably east of the radio core. The ICRF2 position of 0554+242 is located between the two components, about 0.6 mas from the core position. The difference in the ICRF2 position and the VLBA 8.6-GHz position is likely caused by the motion of the eastern component away from the core over the last ten years.

The source structure of 0601+245 is complex, but analysis of the 23 and 43-GHz images suggests that the radio core is associated with the component at the eastern part of the emission. The peak of the VLBA 8.6-GHz image (hence its position) is near the middle component which has a relatively steep spectral index and would thus dominate the emission at 8.6-GHz. The ICRF2 position is displaced about 0.7 mas to the west of the radio core. Without a detailed reanalysis of the many ICRF2 observations that contributed to the position determination of this source, the cause of the displacement cannot be ascertained. It is possible that its position may be weighted from previous observations when the western component was brighter and closer to the radio core.

4. Summary

Using phase referencing at 43-GHz on four close sources, the relative positions of the sources were obtained to about 0.02 mas accuracy. The radio cores of the sources were identified, but 43-GHz and 23-GHz VLBI observations over one year were required to determine the location of the radio core. The relative positions of the radio cores in the four sources remain constant to within 0.02 mas over the year.

The comparison of the ICRF2 positions with the radio images obtained with the VLBA at 43-GHz and 8.6-GHz show structure-induced offsets between the ICRF2 position and that of the radio core. These offsets can be as large as 1.0 mas and vary with time. The development of a celestial reference frame at frequencies higher than 8.6-GHz would alleviate the positional error induced by structure, and recently observations to determine an all-sky catalog at 23 and 43-GHz were initiated for this reason [3, 4]. Future comparison with GAIA will also require the location of the radio core.

References

[1] Fey, Alan L., Gordon, David, & Jacobs, Christopher S. 2010, IERS / IVS Working Group, "The Second Realization of the International Celestial Reference Frame by Very Long Baseline Interferometry", IERS Technical Note No. 35: http://www.iers.org/IERS/EN/Publications/TechnicalNotes/tn35.html

[2] Mioduszewski A. & Kogan, L. 2010, AIPS memo 110
ftp://ftp.aoc.nrao.edu/pub/software/aips/TEXT/PUBL/AIPSMEM110.PS

[3] Charlot, P., Boboltz, D. A., Fey, A. L, Fomalont, E. B., Geldzahler, B. J., Gordon, D., Jacobs, C. S., Lanby, G. E., Ma, C., Naudet, C. J. et al. 2010, AJ, 139, 1695

[4] Lanyi, G. E., Boboltz, D. A., Charlot, P., Fey, A. L., Fomalont, E. B., Geldzahler, B. J., Gordon, D., Jacobs, C. S., Ma, C., Naudet, C. J. et al. 2010, AJ, 139, 1695

[5] Kovalev, Y. Y., Lobanov, A. P., Pushkavev, A. B. & Zensus, J. A. 2008, A&A, 483, 759